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A study on the deformation characteristics of ballasted track at structural transition zone by multi-actuator moving loading test apparatus

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ABSTRACT

At a structural transition zone between concrete structure and embankment, settlements of ballasted tracks generally become larger than those in a general section. To investigate the deformation characteristics of ballasted track at the transition zone, scale model tests using multi-actuator moving loading test apparatus were carried out. This test apparatus is equipped with sixteen electric–hydraulic actuators to simulate a moving train load traveling on the rails. In the test case without any buffering structure at the transition zone, large local settlement appeared even under the condition of constant moving load without any dynamic wheel load change. Conversely, by installing an approach block (wedge-shaped backfill with well graded and well compacted crushed stone) at the transition zone, local large settlement did not appear. Similarly by installing an approach slab (reinforced concrete slab) or a resilient mat (resilient polyurethane mat installed on the concrete structure), settlement at the transition zone became less than that in the case without any buffering structure.

Introduction

In railway ballasted tracks, track irregularities induced by repeated train load at the structural transition zones generally become larger than those in the general section. For instance, at structural transition zone between bridge and embankment, settlement of sleepers become larger than that in the general section and hanging sleepers are generated at the backfill behind the bridge abutment. Fig. 1 shows typical defect at the structural transition zone. At this location, a concrete box culvert is installed in embankment without any buffering structure for the transition zone. In such situation, settlement of ballasted track at the transition zone becomes much larger than that in the general section. When the large local settlement of the sleeper was induced at the transition zone, ballast particles appear on the surface of the sleepers because the sleepers are subsiding into the ballast. Hanging sleeper in Fig. 1 shows the ballast particles appeared on the surface of the sleepers.

Such problems at the transition zone are roughly divided into two different types of mechanism. The first type is induced by permanent settlement of the embankment. It is due to residual deformation of the embankment itself by repeated train load or consolidation of natural supporting ground beneath the embankment. Immediately after the opening of Tokaido Shinkansen (high speed line between Tokyo and Osaka), this kind of deformation induced serious problems in the maintenance of ballasted track at transition zone.

The second type is induced by resilient deformation of the embankment under train load. After several decades after construction, permanent deformation of

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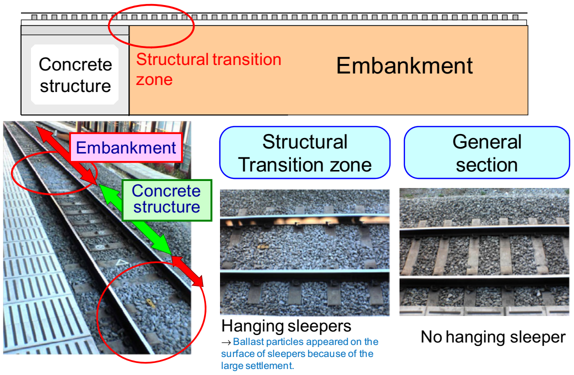

Fig. 1. Typical defect at the structural transition zone.

embankment by train load or consolidation of natural ground beneath the embankment becomes converged. Nevertheless, settlement and track irregularity of ballasted tracks generally still stay large at the transition zone. It is due to the difference of supporting stiffness between the embankment and a concrete structure. Because such sudden change of supporting stiffness continues for quite a long term, problems at the transition zone continue even after decades after construction.

To decrease such extensive track irregularity at the structural transition zone, the Japanese design standard for the earth structure prescribes to install a wedge-shaped backfill made of high-strength material, namely what we call ‘approach block’. Approach blocks are made of well graded and well compacted crushed stone or cement treated gravel. By installing such approach block, track supporting stiffness gradually changes from the concrete structure to the embankment. As a consequence, on new lines constructed based on the design standard, track irregularities at the transition zone become much less. On the contrary, the existing lines which were constructed before the design standard was established, approach blocks were in most cases not installed at the transition zone. Since most of the existing railway lines in Japan were constructed before the first design standard was established in 1978, many transition zones on the existing lines still have the problems of track maintenance.

Problem of maintenance of ballasted track at the transition zone is a general issue in many countries. Woodward et al. (2012) proposed to reinforce ballasted track by polyurethane GeoComposites at the transition zone and carried out a numerical simulation by the finite element method. Fortunato et al. (2014) measured dynamic deformation characteristics of wedge shaped backfill on site and showed that track supporting stiffness gradually increases from the embankment to the concrete structure. Mishra et al. (2014) measured deformation of the embankment at transition zone by Multidepth Deflectometers. Furthermore, several numerical approaches were carried out for the issue at the transition zones (Varandas et al., 2011, 2014; Wang et al., 2014; Yang et al., 2014).

The conventional method to evaluate deformation characteristics of the ballasted track by loading test was the fixed point loading by which cyclic load is applied by fixed actuators. This method was widely applied to a real scale ballasted track loading test. Sekine et al. (1994) applied the fixed point cyclic loading test to evaluation of the effect of roadbed improvement by using honeycomb shaped geotextile cell. Ishikawa and Namura (1995) carried out the fixed point cyclic loading test on single sleeper ballasted track to measure the pressure distribution on the bottom surface of sleeper.

To investigate the deformation characteristics of the ballasted track at the transition zone in laboratory test, it is necessary to apply repeated moving load because the problems of the ballasted track at the transition zones are induced by the loads moving on discontinuous stiffness substructures. The fixed point loading test which is the conventional cyclic loading test method does not make sense to investigate the deformation characteristics of the ballasted track in such a kind of situation.

Hirakawa et al. (2002), Momoya et al. (2005) and Ishikawa et al. (2011) discussed the difference between the fixed point loading and the moving loading on railway track under quasi-static condition by 1/5 scale model tests using moving wheel loading test apparatus. However, in those tests, number of repeated loading was limited because moving loading was executed by a reciprocating moving wheel in the test apparatus. Jiang et al. (2012) developed a full scale moving loading simulation system equipped with eight actuators in 5 m lengths. This test apparatus is such a remarkable one as it can carry out full scale moving loading tests on an embankment model. However, because of the limitation of the test apparatus size and the number of actuators, it is considered to be difficult for this system to evaluate the deformation characteristics of the ballasted track at the transition zone.

To cope with the above limitations for the moving loading test, Muramoto et al. (2008) developed a multi-actuator moving loading test apparatus (MOSCCOM: Moving-load Simulator with Concurrently Controlled Multi-actuators). This test apparatus applies moving load on a 1/5 scale model railway track. In this study, repeated moving load was applied to the scale model by using MOSCCOM to investigate the deformation characteristics of the ballasted track at the transition zone. Furthermore, effective countermeasures to reduce the track irregularities at the transition zone were proposed based on the result of the model test.

The velocity of the moving load was 2.89 km/h, which corresponds to 14.45 km/h in the full scale. Therefore, quasi-static deformation at a relatively low train speed was evaluated in this test. In general, it is considered that the deformation of the ballasted track is affected by the vibration induced by high train speed. In this paper, a quasi-static deformation characteristic was discussed by 1/5 scale model test.

Moving loading test method

Moving loading test apparatus

Fig. 2 shows the overall view of MOSCCOM which is equipped with sixteen electric–hydraulic actuators to simulate moving train load. Each of these electric–hydraulic